

Ultra-cold Atom Storage Rings

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Outline

- What are ultra-cold atom storage rings?
- Physics of ultra-cold atoms
- Beam dynamics of the atom ring.
- Applications of atom storage rings
- UK research groups working in this area.

What are ultra-cold atom storage rings?

Georgia Tech

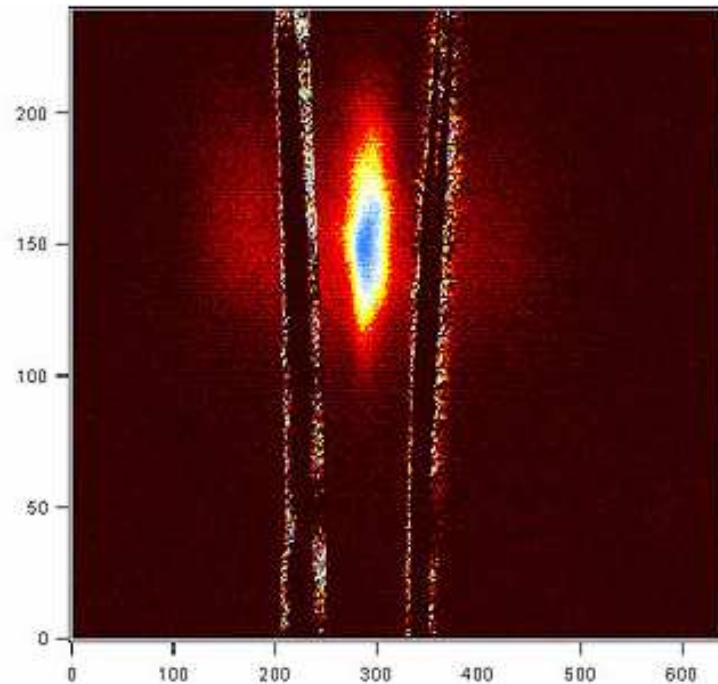
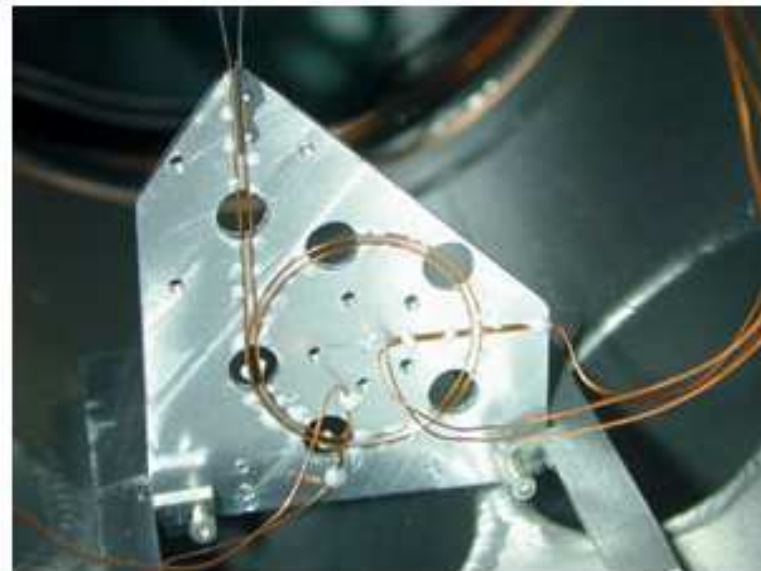


Image shows cloud of atoms between guide wires of the Nevatron, the world's smallest atom storage ring.

GEORGIA TECH'S NEVATRON



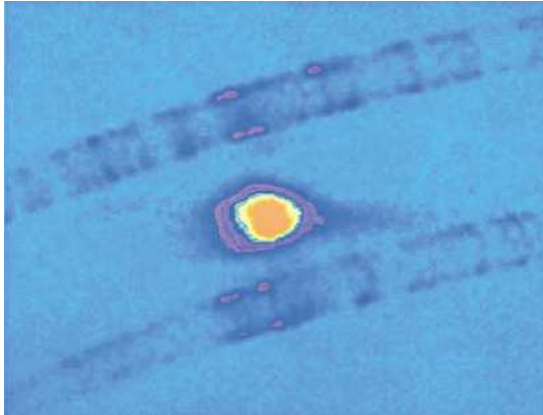
Familiar geometry, different scale: Georgia Tech's Nevatron measures just 2 cm across.

Why are ultra-cold atoms interesting?

- Ultra-cold atoms behave as a matter wave, just as photons behave as light wave.
- The use of matter wave - instead of light - in interferometry and laser has been demonstrated. It has potential for much higher precision because of the mass.
- It has so far been used to measure acceleration, test general relativity, perform low energy collisions, manipulate quantum degenerate gases, ...
- Atom rings offer a means to make the system compact, with potential for commercialisation.

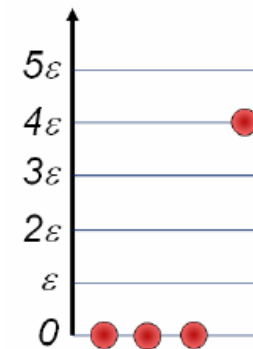
Physics of ultra-cold atoms

At very low temperatures,
Rubidium gas forms a coherent wave.



Sauer, *et al* (2001) Georgia Tech

Andy's statistical physics
lecture notes



The Bose-Einstein condensation

The particles in the ground state for $T < T_B$ constitute a *Bose-Einstein condensation*. The temperature T_B is known as the *Bose temperature*.

Below a critical temperature T_B in a system of indistinguishable bosons, the population of the ground state in a series of quantised states becomes very large, and discontinuous with the populations of the excited states. The extra population of the ground state is the Bose-Einstein condensation.

Cooling with a small laser - No cryogenics required

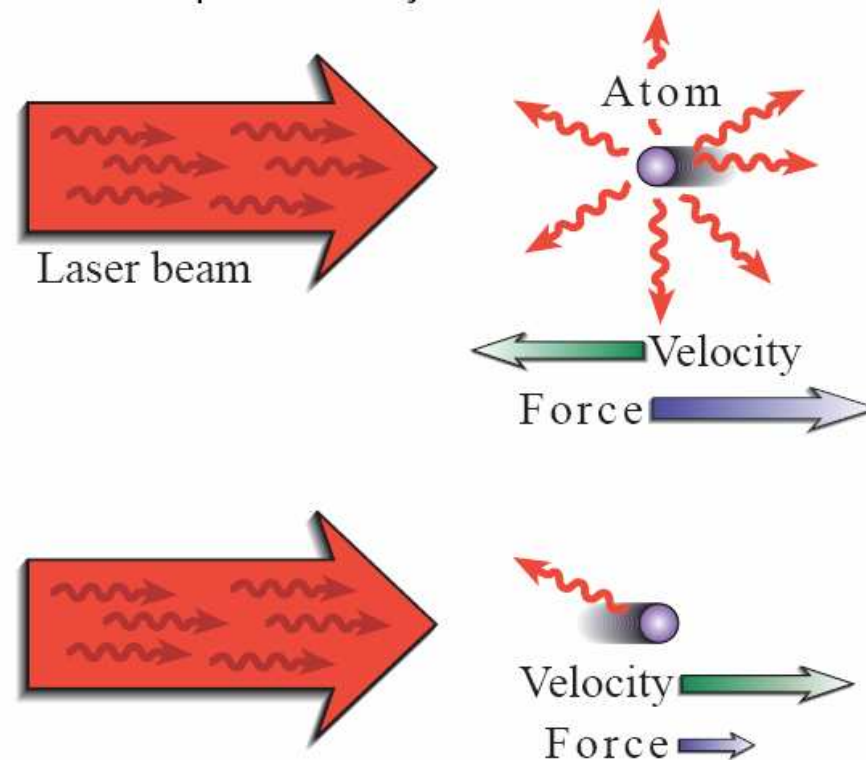
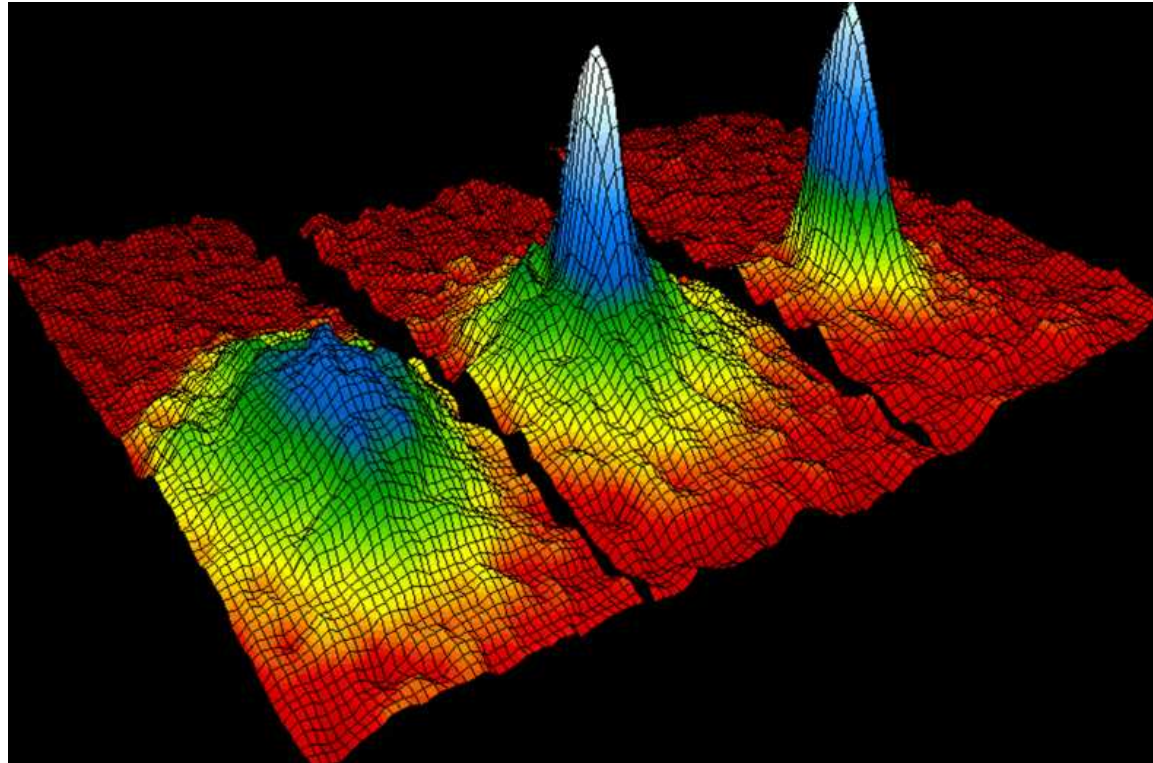


Figure 2. With the laser tuned to below the peak of atomic resonance. Due to the Doppler shift, atoms moving in the direction opposite the laser beam will scatter photons at a higher rate than those moving in the same direction as the beam. This leads to a larger force on the counter-propagating atoms.

Advanced Optics Laboratory, Ben Gurion University, Israel

BEC: Bose-Einstein Condensate



Wikipedia

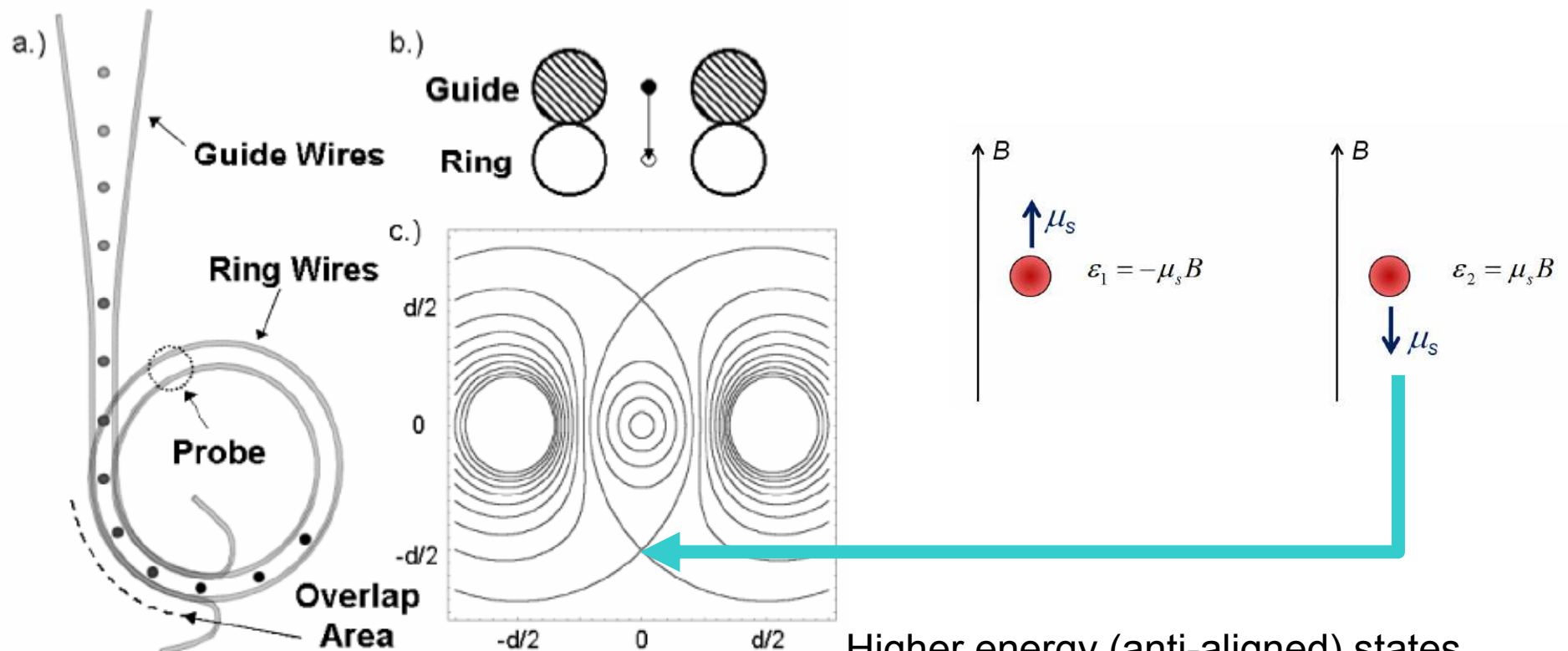
Velocity-distribution data of a gas of [rubidium](#) atoms, confirming the discovery of a new phase of matter, the Bose–Einstein condensate.

Left: just before the appearance of the Bose–Einstein condensate.

Center: just after the appearance of the condensate.

Right: after further evaporation, leaving a sample of nearly pure condensate.

Beam dynamics of the atom ring.



Sauer, *et al* (2001) Georgia Tech

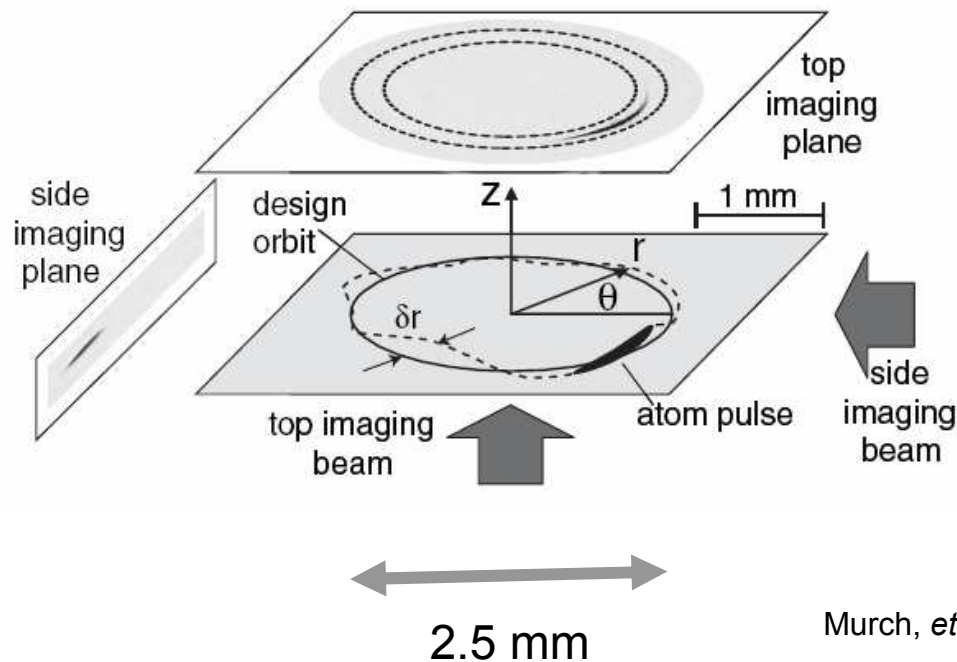
$$U = \mu_s B$$

is minimum, because $B = 0$.

Betatron Resonances

Betatron resonance (in the transverse direction) is found the remove energy from the longitudinal motion, lowering its temperature to the pK range.

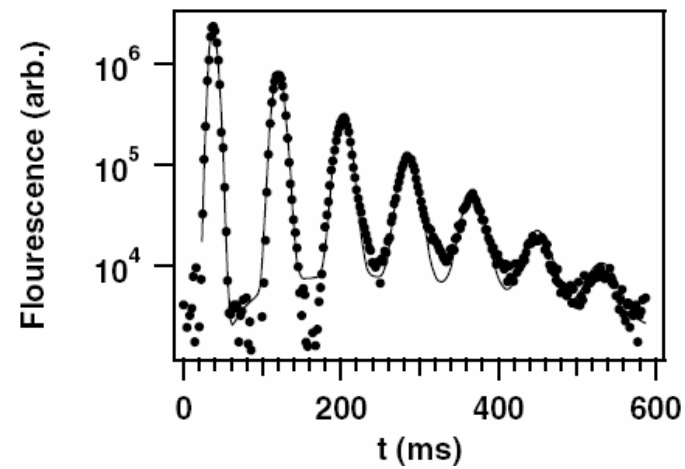
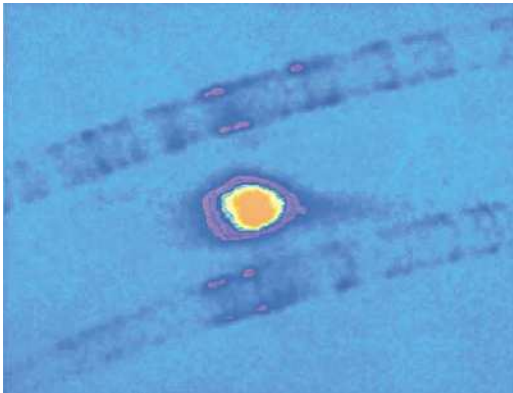
This can be used to improve precision measurements of rotation, fundamental constants, etc.



Murch, *et al* (2006)

Beam lifetime

Atom beams suffer from scattering from residual gas in the vacuum, as well as leakage from the ring because of poor focusing.



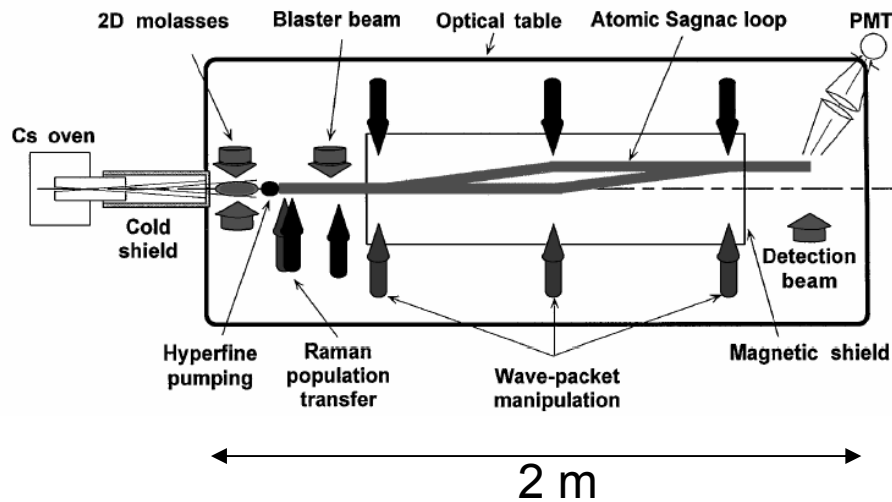
Sauer, *et al* (2001) Georgia Tech

Applications of atom storage rings

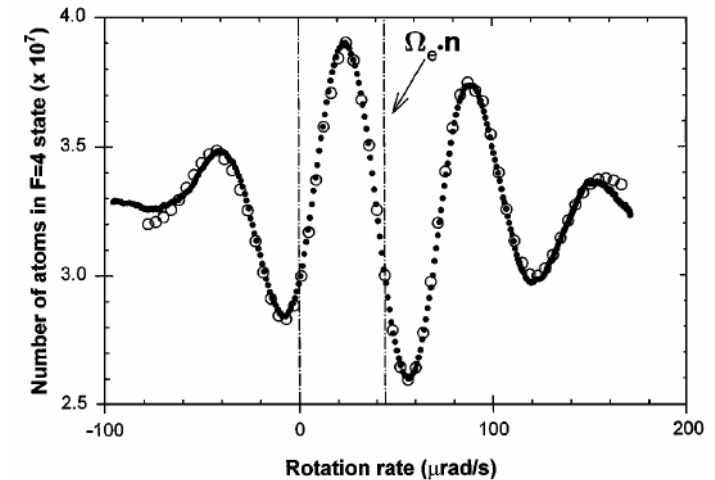
- Apart from manipulation of ultra-cold atoms for experiments in general, a niche application is in inertial guidance.
- High precision measurements of rotation and acceleration is important in air vehicles and space crafts. The atom ring offers the potential for a compact, portable system.
- Another area is storage and manipulation of cold molecules for molecular physics experiments.

Measuring rotation very precisely

Atom interferometer in Stanford University



Rotation causes shift in fringe pattern.



Gustavson, *et al* (1997)

Interférométrie à Source Cohérente pour Applications dans l'Espace

Measuring acceleration in outer space



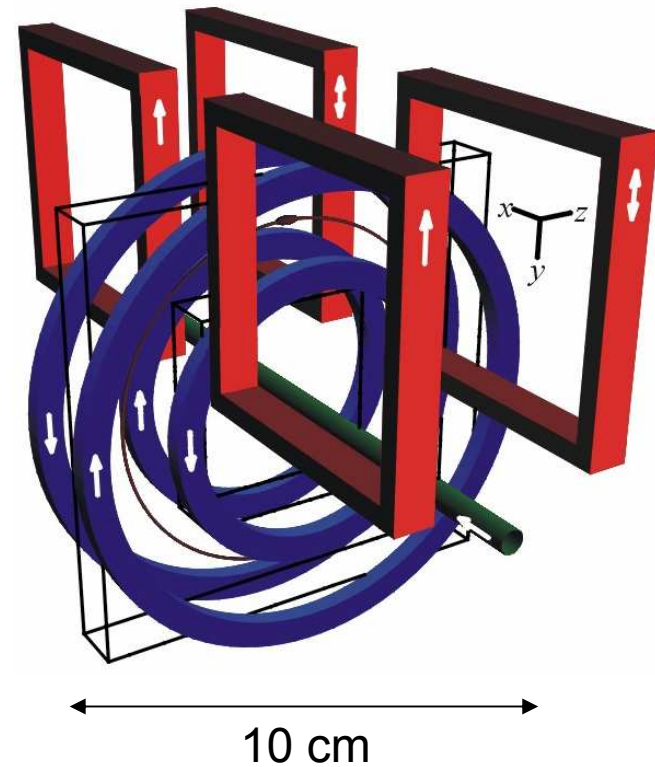
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Storage Ring for BEC

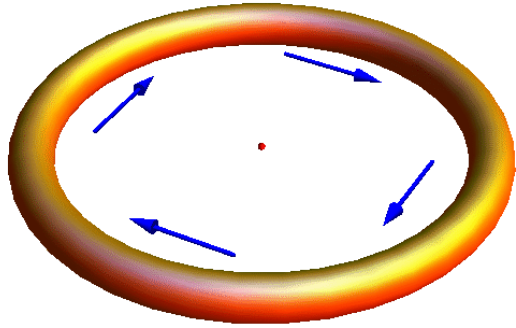
EPSRC funding 2008

To build atom storage ring for high precision measurement of rotation and acceleration.

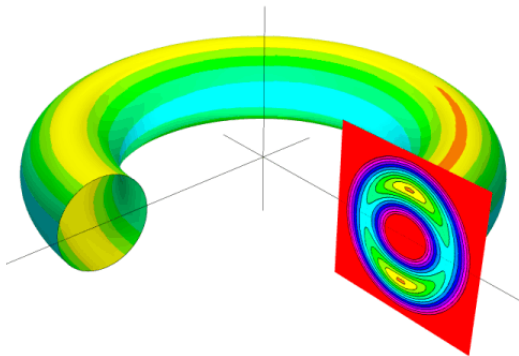
Strathclyde University



UK research groups working in this area



Strathclyde University



Nottingham University



Thank You